Managing Your Chilled Water System for Energy and Water Efficiency

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ChE, Water Treatment & Energy Management

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

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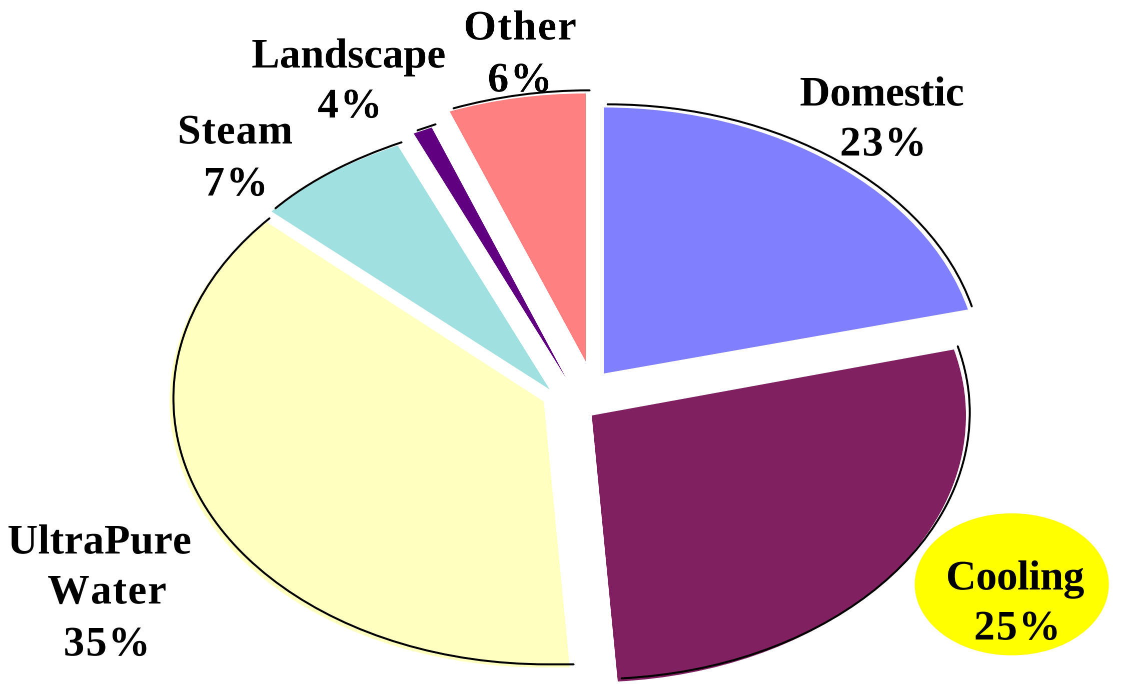
Sandia National Laboratories Audit Findings



Cooling Tower Study

Sandia has 23 cooling towers serving 42 chillers.

Estimated makeup water for blow-down, evaporation, and drift ~ 75.5 million gallons per year.

Research ways to increase cycles of concentration resulting in reduced water and chemical use

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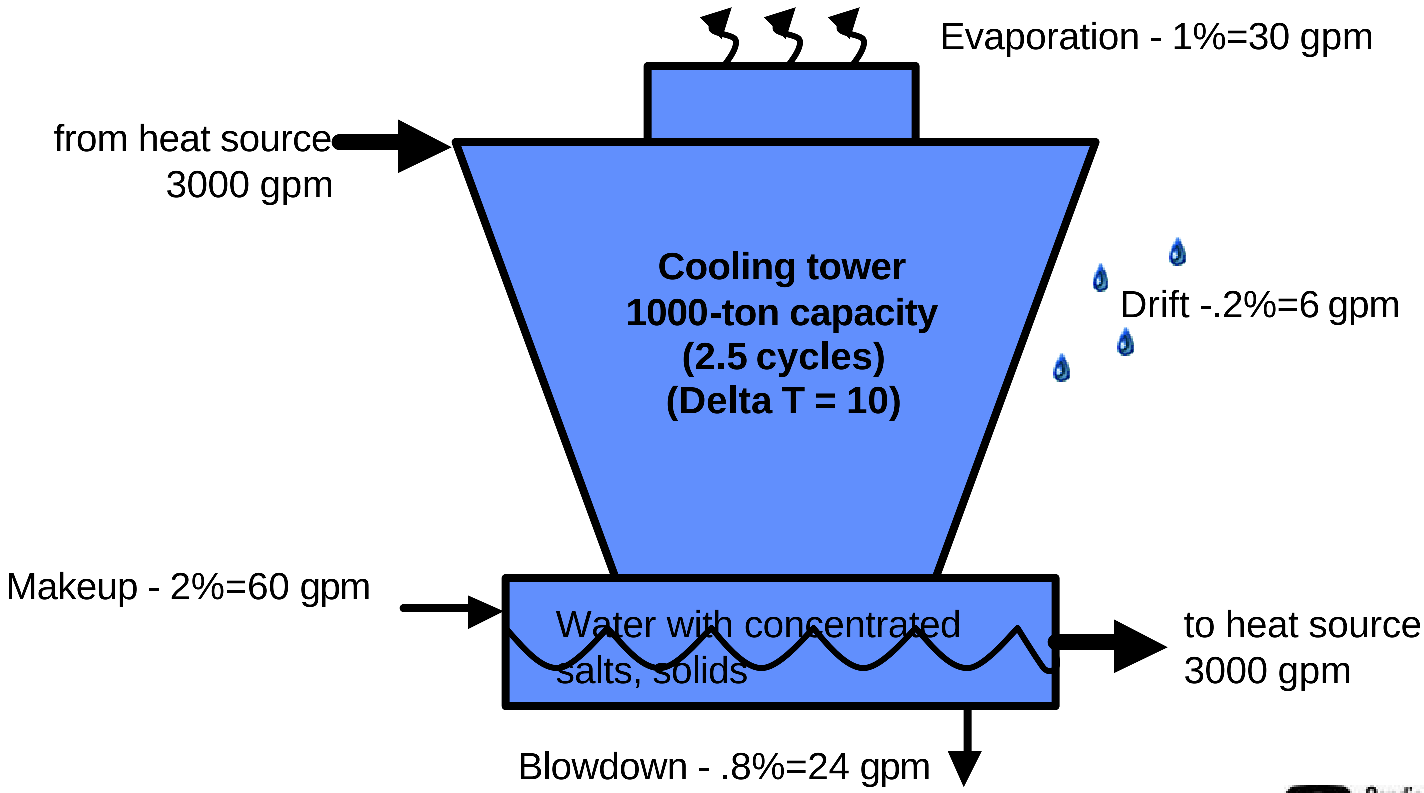
Cooling Tower Water Balance

(As a percentage of circulating flow)



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Cooling Tower Terminology and Equations

- Makeup Water = Evaporation + Drift + Blowdown
- Concentration Ratio (CR) or Cycles of Concentration = Makeup / Blowdown
- Blowdown = (Evaporation + Drift) / (Concentration Ratio -1)
- % Blowdown or Chemicals Conserved = (CR2 - CR1) / (CR2 - 1)
- Makeup = (lbs. chemical used x 10^6) CR / (ppm dose rate x chemical density in lbs. per gallon)
- 2.5 to 3.0 gpm of evaporation per 100 tons of cooling
- 300 gpm of tower water circulating per 100 tons of cooling

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Cooling Tower Water Use Calculations

Cycles **2.8**
PPM Product **75**

	Chemical lbs.	Makeup gals.	Blowdown
806	1,034	4,628,617	1,653,078
807	517	2,314,309	826,539
836	1,175	5,259,792	1,878,497
840	564	2,524,700	901,679
850	3,102	13,885,851	4,959,233
858	3,619	16,200,160	5,785,771
864	282	1,262,350	450,839
870	282	1,262,350	450,839
890	517	2,314,309	826,539

Blowdown = (lbs of chemical used * 1,000,000) / (ppm of chemical * 8.34 lbs. per gallon)

Total Water Used = Blowdown * Cycles

Challenges & Solutions - Cooling Tower Project

- **“You can’t save much water because 80-90% of the water is lost to evaporation”**

Cycles	2.5	3	4	5
Evaporation	45,300,000	45,300,000	45,300,000	45,300,000
Blowdown	30,200,000	22,650,000	15,100,000	11,325,000
Makeup	75,500,000	67,950,000	60,400,000	56,625,000
Blowdown Saved from 2.5 Cycles		7,550,000	15,100,000	18,875,000
% BD Saved		25%	50%	63%
% of Makeup that is Evaporated	60%	67%	75%	80%

Evaporation stays the same for the same load
BD = E/(CR-1)

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Potential for Site-wide Savings at Cooling Towers

	Gallons per Year	Pounds Chemical
At 2.5 Cycles	75,500,000	16,500
At 4.0 Cycles	60,400,000	8,250
Savings	15,100,000	8,250
	Blowdown Saved	Chemicals Saved

ESTIMATED SAVINGS		
Water Savings	1.25/1000 gallons	$18,875
Sewer Savings	1.25/1000 gallons	$18,875
Chemical Savings		$33,000
		$70,750

Water Savings as % of Total Water Use = (4-2.5)/((2.5(4-1)) = 20%
% Chemical Savings = 4-2.5 / (4-1) = 50%

Challenges and Solutions - Cooling Tower Project

- "If you run a test on this tower you run the risk of destroying a chiller that supports the entire complex!!!"
  - This is catastrophizing and it is a very powerful barrier
  - Put the risk in perspective
    - A recent network computer failure knocked down our entire system for over 24 hours
    - The existing chilled water system was designed to be 100% redundant with one of everything (tower, chiller, pumps etc.)
  - What is the risk that the existing system can fail prior to any changes
    - Stuck blow-down valve
    - Conductivity meter going out of calibration

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Cooling Tower - "Control" Case

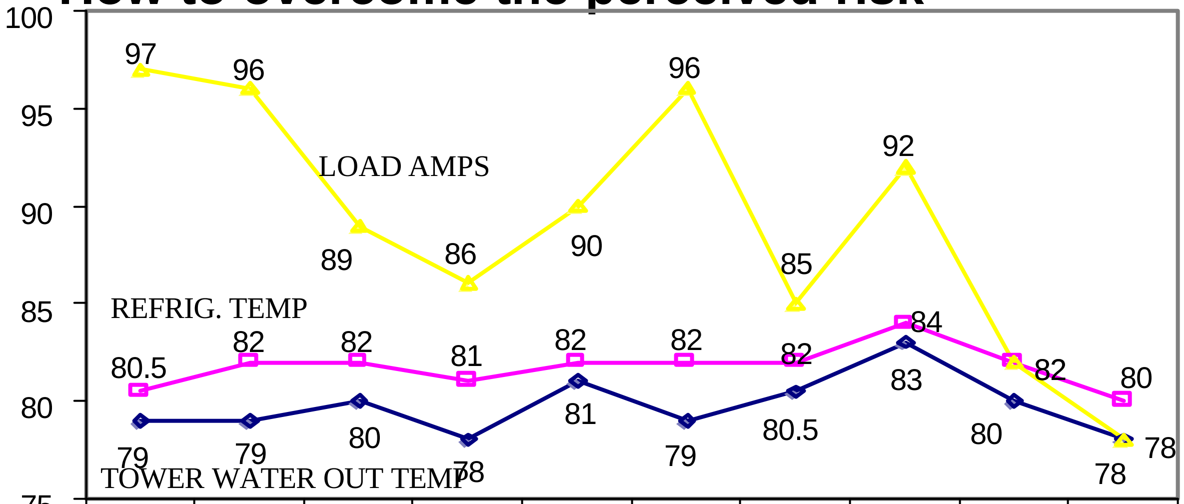
- Two Identical Redundant Towers at Bldg. 850
- Would our test result in a condition never before experienced?
- Used Adjacent Tower at Bldg 890 as "Control" case

Challenges and Solutions - Cooling Tower Project

- **How to overcome the perceived risk**
  - **Install deposition monitor**

Challenges and Solutions - Cooling Tower Project

• **How to overcome the perceived risk**



DATE	6/19	6/22	6/22	6/23	6/23	6/24	6/24	6/24	6/24	6/25
Tower Water Out	79	79	80	78	81	79	80.5	83	80	78
Saturated Refrigerant	80.5	82	82	81	82	82	82	84	82	80
Load Amps	97	96	89	86	90	96	85	92	82	78
APPROACH	1.5	3	2	3	1	3	1.5	1	2	2

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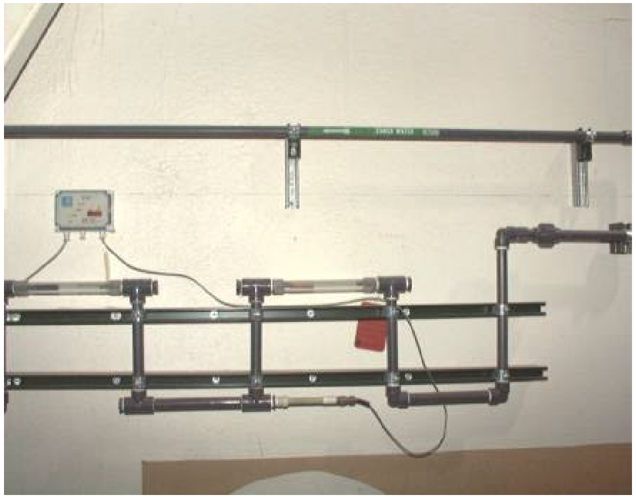
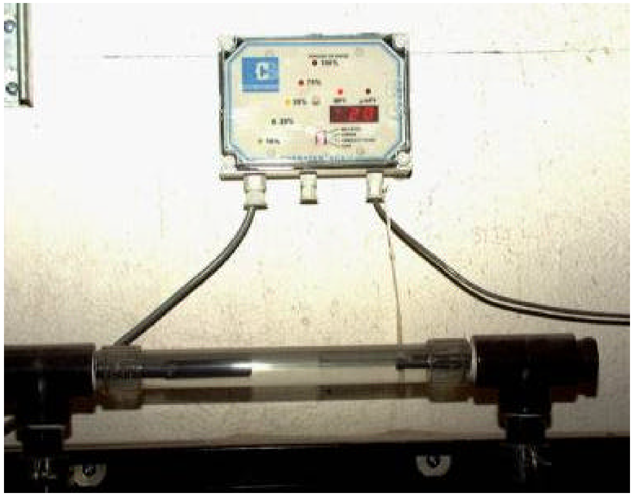
Challenges and Solutions - Cooling Tower Project

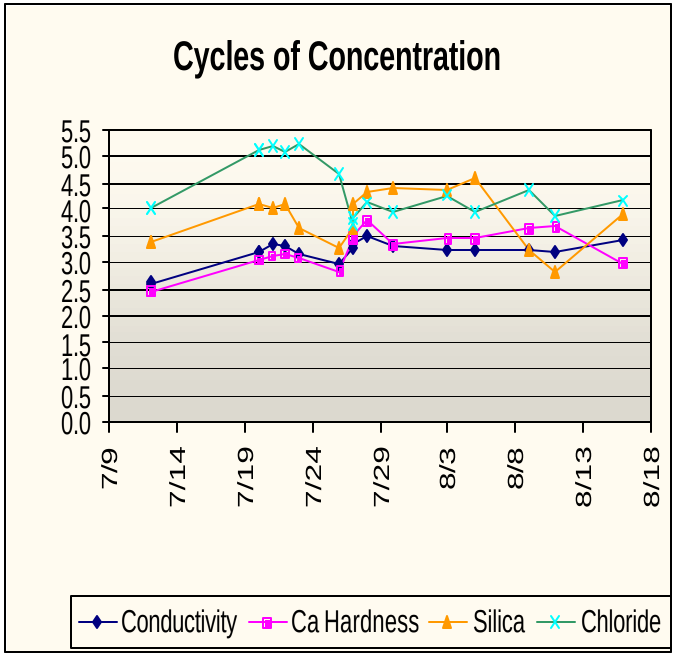
- How to overcome the perceived risk
  - Install corrosion monitor and coupon rack

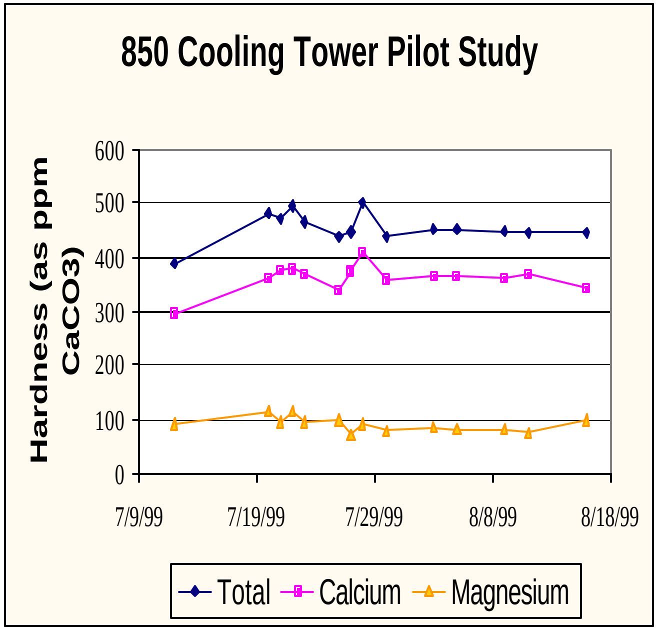




Challenges and Solutions - Cooling Tower Project

- **How to overcome the perceived risk**
  - **Collect water chemistry data**





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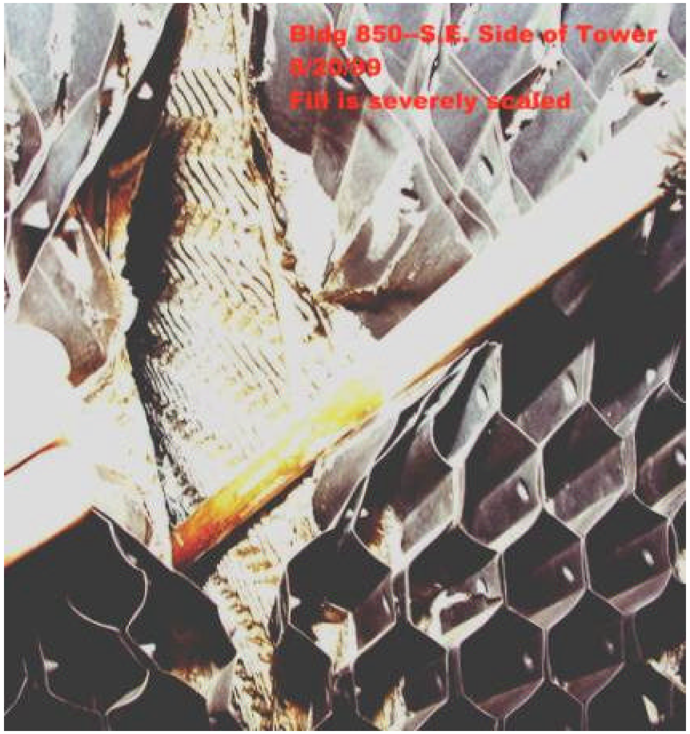
Tower Fill Severe Scaling

Towers are designed for set flow rate as well as the chillers

Strap on flow meter for flow rate

Cooling Tower - Fill Scaling Comparison (1999)

Test Tower - Scale



"Control" Tower - Scale

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Tower Fill - What Caused the Scaling????

Smooth Flow

Turbulent Flow

Tower Fill - What Caused the Scaling????

•Total circulating flow was below design standard

•Poor water distribution to the tower fill

•Not enough flow on the outside edge of the fill to keep the bottom portion wet

•Turbulent flow in the distribution pan keeps water from the front row of nozzles

COOLING TOWER STUDY RESULTS

- What we thought would take 6 months to figure out took 18 months (and is still on-going!)

- What we thought would be the limiting factor isn't
  – Chiller scaling was not the limiting factor
  – Tower fill scaling became the limiting factor

COOLING TOWER STUDY RESULTS

- Studying a system leads to finding hidden operational problems
  - We found water flow to be 25% below design requirements
    - Resulted in improved system operations and saving $10,000 per year in electrical costs
    - Fixing the flow issue was key to meeting goal of increasing cycles of concentration
    - Operations sees the benefit in having us look at their equipment

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COOLING TOWER STUDY RESULTS

- **At low cycles of concentration of 2.5 we could reduce recommended chemical dose rate 30%**

- **You can collect so much data that you miss the forest for the trees - but the data is essential if you want to avoid anecdotal results**

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Reclaim Spent Rinse-Water for Cooling Towers

Send portion of spent microelectronics water to adjacent cooling towers

High make-up water quality allows increasing concentration cycles from 2.8 to 10

Intel had already pioneered the way

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Reclaim Spent Rinsewater Analysis

Microelectronics Spent Rinsewater (Acid Waste Neutralized)	Worst Case During Resin Regeneration (ppm as $CaCO_3$)	Random Sample (ppm as CaCO3)	Existing Well Water
Calcium as CaCO3	10	1.5	100-130
Magnesium as CaCO3	3	0.4	20-45
Sodium	860	140	
Alkalinity	0.5	12	100-140
Silica	8	1	40-55
SO_4	72	10	
Chlorides	730	120	35-50
Ammonia	10	10	
TDS	1420	220	125-140
pH	9	9.2	
Resistivity		2600 ohms-cm	360-400 mmhos

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Reclaim Spent Rinse-Water for Cooling Towers

Annual Water Savings

- Reclaim water can be used at 10 cycles
- Savings is equal to the well water that would have been used at 2.8 cycles
- A new facility was already added to this cooling tower system and a future facility is planned to be added
- Back calculate equivalent well water use

$$\boxed{\frac{\text{Water Used at 10 Cycles}}{1-((CR2-CR1)/(CR1)(CR2-1))}} = \boxed{\frac{15{,}000{,}000}{.714}}$$

- Well Water Saved = 21,000,000

Reclaim Spent Rinse-Water for Cooling Towers

	Unit Cost	Gallons	Total
Water Use	$1.25/1000	21,000,000	$26,250
Sewer Discharge	$1.25/1000	21,000,000	$26,250
Chemicals			-$10,000
Operations			$0
			$42,500
Total Project Costs			$165,000
Simple Payback in Years			3.9

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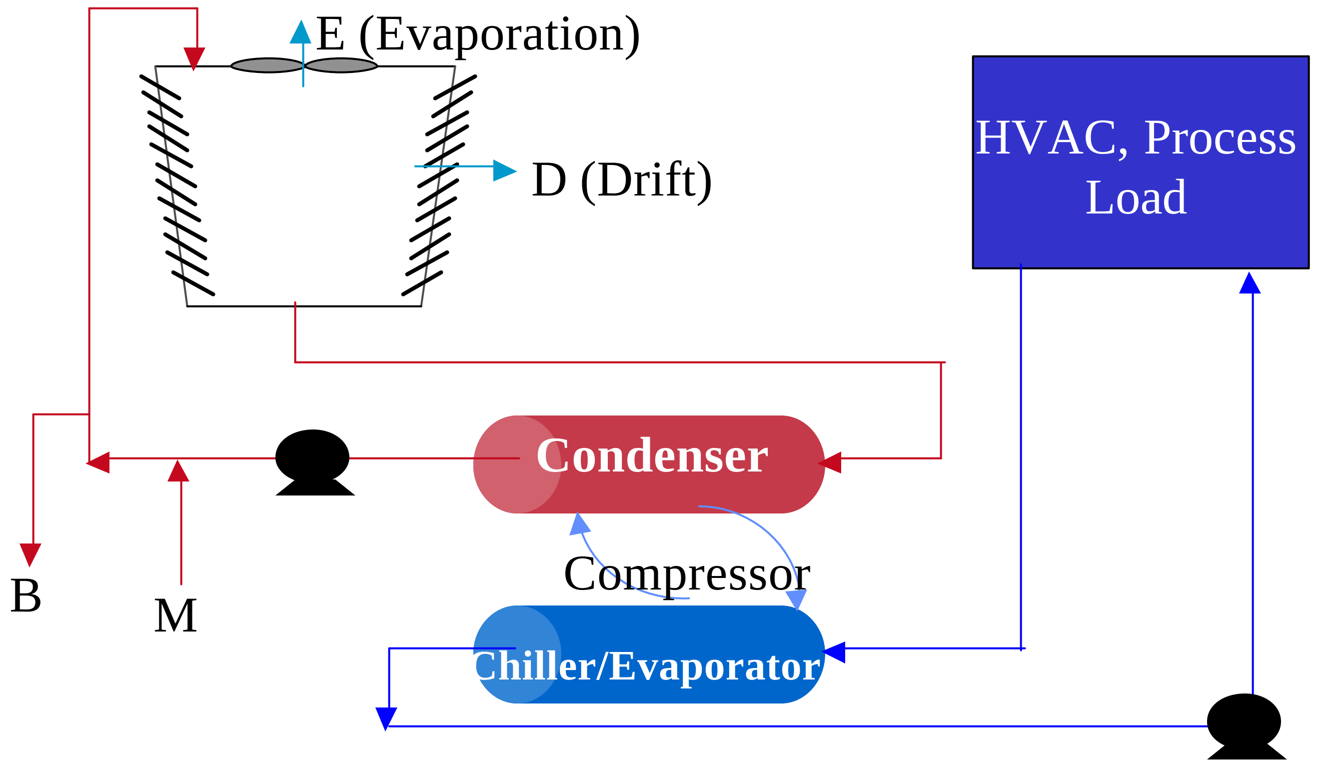
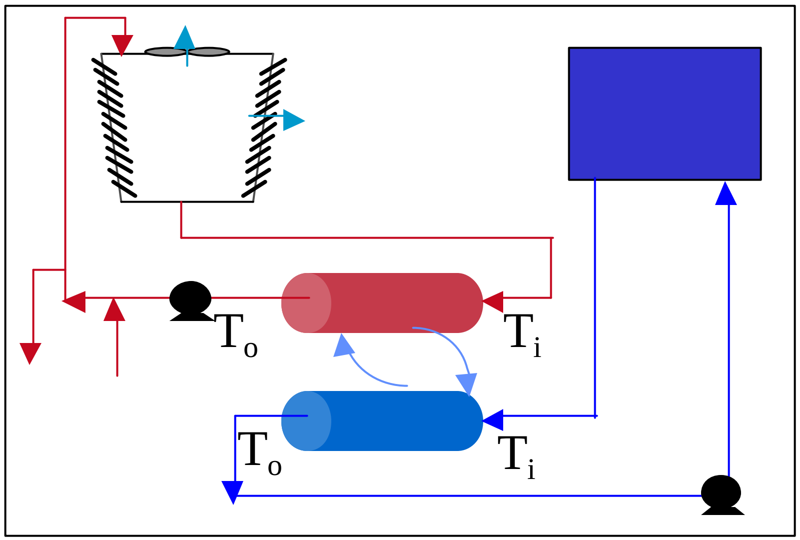
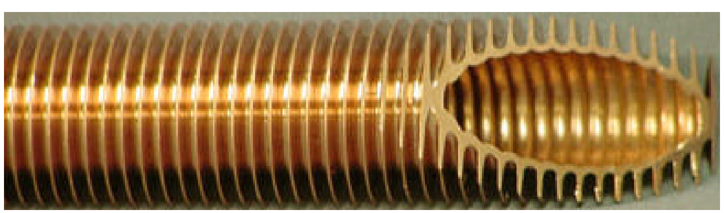
Chilled Water System Diagram



Chiller/Condenser Operation & Parameters





Example of “Enhanced” tube from Wolverine Tube, Inc

- **Approach Temp, ΔT**
- **Surface Area Effects**

  $Q = m \cdot C_p \cdot (T_o - T_i)$, (BTU/hr)

  $= U \cdot A\ (\Delta T)$

  $= 1/R_{total}\ (\Delta T)$

  $m = V \cdot \rho$, (lb/hr)

  $V = v \cdot A$, (ft^3/hr)

- **Problem areas**
  - **“Enhanced” tubes**
  - **Low Flow Areas**
  - **Tube Surfaces**
  - **Shell-side**

Water Parameters

- **ALL WATER IS CORROSIVE**
- **MUST Know:**
  - **Contaminants in the tube/shell fluids**
    - **(e.g. silica level, mineral content, metals content, pH, etc.)**
  - **Chemical water treatment capabilities**
    - **How much silica, calcium, iron can be kept in solution?**
    - **What are the limits on alkalinity, temperature, pH, etc?**
  - **Materials of Construction**
    - **Are all the materials of construction (tube metal, etc) compatible with both the fluid type AND the water treatment chemicals?**

Possible Chiller/Condenser Problems

- **Both Shell-side and Tube side**
  - **Scaling – Calcium deposits, silica, etc. on surfaces**
  - **Corrosion – Galvanic, Underdeposit, etc.**
  - **Biological Growth – slime, MIC**
  - **Fouling – Actual degradation of surface**
- **Incompatible Materials of Construction**
- **Design Issues**

There are many possible problems in a chilled water system – the key is to mitigate their risk.

Chiller/Condenser Operation & Parameters

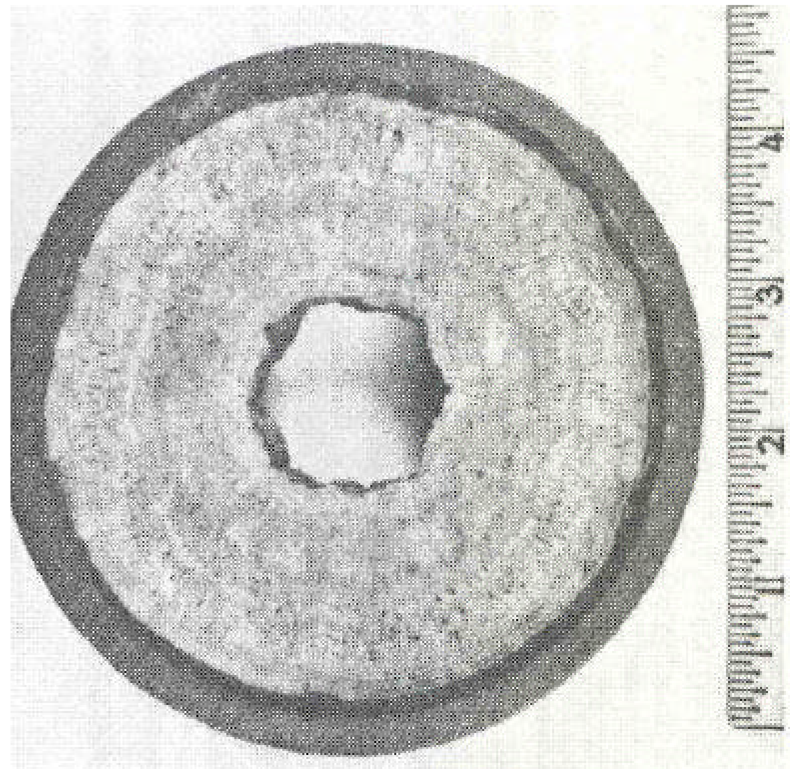
Microbiologically Induced Corrosion on Carbon Steel

Source: AWT Technical Reference and Training Manual, 2002; © NACE Int.

Chiller/Condenser Operation & Parameters

Water Carrying pipe plugged with Calcium Carbonate

Source: AWT Technical Reference and Training Manual, 2002;



Mitigation of Chiller/Condenser Problems

- **Operational**
  - **Corrosion monitoring – Install corrosion coupons or monitoring devices.**
  - **Downtime: Have good lay-up procedure for long periods of time**
  - **Chiller Rotation: Good for reducing excessive downtime & keeps water treatment effectiveness**
  - **Pumps: Correctly sized?**
  - **System Inspections: Must be performed regularly**
  - **System Leaks – Metering can really help to isolate!**

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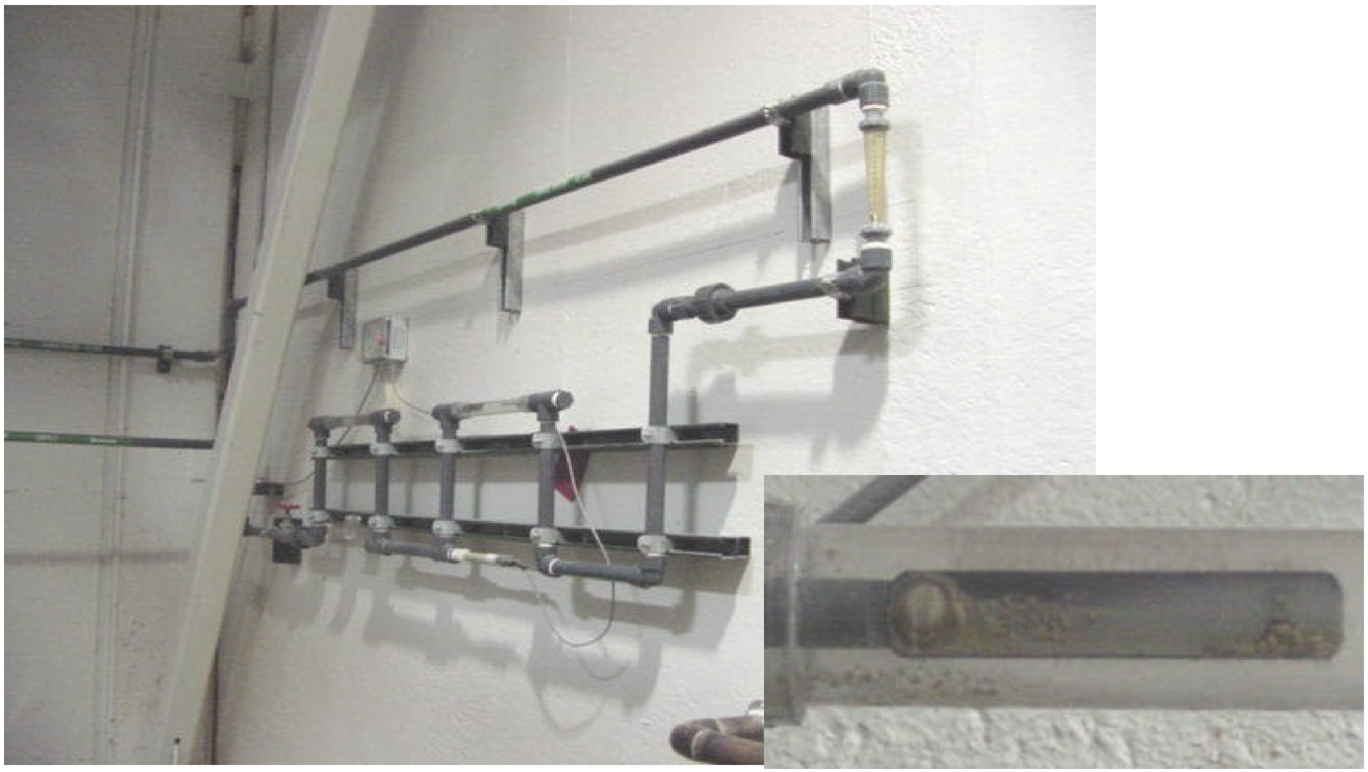
Mitigation of Chiller/Condenser Problems



Corrosion coupon rack at SNL w/close-up

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Mitigation of Chiller/Condenser Problems

Corrosion Coupons before and after cleaning. Exposed for 6 months to oxidizing biocide

Source: A Practical Guide to Water Treatment Chemicals®, 3rd quarter 1998, Puckorius & Associates

Mitigation of Chiller/Condenser Problems – Chemical Treatment

– **Condenser Water (Open System)**

- **Scale Inhibition**
  - <u>Types of Programs:</u> Phosphate/Phosphonate, Tolytriazole, zinc, Polymers, etc.
  - <u>Ranges:</u> Depends on type of Phosphate/Phosphonate, etc. but Water Treatment contractor should be able to give you a recommended range
  - <u>Watch the cooling tower:</u> this is the first place (usually) that scaling will occur
- **Biocides**
  - <u>Types of Programs:</u> Oxidizing (Bleach, Cl_2, Br_2, Stabilized Mixtures), Non-Oxidizing (Quat. Amines), Additional dispersant
  - <u>Ranges:</u> Oxidizing: 0.5-1.5 Free Chlorine Shock Feed, Non-Ox: depends
  - Watch for algae, slime, etc on cooling tower.

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Mitigation of Chiller/Condenser Problems – Chemical Treatment

– Chiller Water (Closed Loop)

- Scale Inhibition
  - Types of Programs: Nitrate/Borate, Molybdate, etc.
  - Ranges: Depends on system pH, temperature, metallurgy, etc. Water treatment contractors should give recommended range for hot and cold water closed loops- they should be different!
  - Sample often to check chemical residuals and contaminants
- Biocides
  - Types of Programs: Oxidizing (gluteraldehyde), Non-Ox (Quat. Amines)
  - Ranges: Depends on biocide type
  - Sample often to check chemical residuals and bio-growth.
- Make sure that water treatment chemicals are compatible with materials of construction!

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Mitigation of Chiller/Condenser Problems

- What to sample and how often?
  - Condenser (Cooling Tower) water
    - Weekly, at a minimum: Check for biocide & inhibitor residuals, conductivity, pH, mass balance, water use (if appl)
    - Monthly biological testing – the more data points you can get, the more meaningful the data.
  - Chiller water
    - Test as often as possible
      - Quarterly tests for chemical residuals, conductivity, pH, and water data (if appl) should be enough
      - Monthly (or more often) testing may be required for problematic systems

Mitigation of Chiller/Condenser Problems – Chemical Treatment

– ***Do you need expensive analyses performed <u>EVERY</u> time?***

- **Not necessarily: Many companies (Hach, LaMotte, Fisher Scientific, etc) offer easy-to-use test kits that are accurate**

- **Problematic systems (both closed and open loops) may require more sophisticated analysis and/or advice from a consultant**

- **Use experts/consultants as needed**

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Chiller/Condenser Efficiency

- **Heat Transfer Equation:**
  - **Q=mCpDT**
- **Scaling/Biofouling**
  - **A layer of $CaCO_3$ 1/16" thick can reduce chiller efficiency by up to 50%!**
  - **The combination of scale or corrosion deposits with biological activity underneath can create serious detrimental effects**
- **Don't overfeed chemicals**
  - **Find the appropriate feed amount of chemical, don't overfeed, don't underfeed.**

Bottom Line: Mitigate problems using proper chiller/condenser operation and maintenance!

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Summary

- Know your system configuration, possible problems
- Know your water quality – what's in it?
  - Does it have a scaling or corroding tendency?
  - Does it have a high metal and/or mineral content?
  - Is it reclaim water?
- Know your materials of construction
  - Is everything (including water treatment chemicals) compatible?
  - Where might problems occur?

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Summary

- Know your water treatment program and be familiar with testing procedures
  - What are the required residuals & limits of each chemical?
  - How often and what to test?
- Look into efficiency improvements when possible